

CHEMICAL MECHANICAL POLISHING METHOD AND APPARATUS FOR CONTROLLING MATERIAL REMOVAL PROFILE

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FIELD

[0001] The present invention relates to manufacture of semiconductor integrated circuits and, more particularly to a method for polishing of conductive layers for planarization and removal.

BACKGROUND

[0002] Chemical mechanical polishing (CMP) of materials has important and broad application in the semiconductor industry. CMP is a widely used technique for planarizing metals and dielectrics as well as other types of layers on semiconductor wafers. CMP is often used to flatten/polish the profiles that build up in multilevel metal interconnect fabrication schemes.

[0003] In a typical CMP process, a substrate such as a semiconductor wafer is mounted on a substrate carrier, often called a head. The wafer surface to be polished is pressed against a polishing pad surface and the pad and the head are moved with respect to each other. This is typically done by rotating the wafer, moving the pad or both. The polishing pad may be a conventional polishing pad or a fixed abrasive polishing pad. Conventional or polymeric polishing pads are usually employed along with polishing slurries including abrasive particles and chemically reactive agents. The surface of a fixed abrasive polishing pad typically includes abrasive particles embedded in a matrix material. During processing, imbedded abrasive particles perform polishing with the help of a polishing chemistry, which may or may not contain abrasive particles.

[0004] Figure 1 illustrates an exemplary prior-art CMP system 10 that includes a polishing pad 12, which may be moved with respect to the wafer 14 that is held by a wafer carrier 16. The polishing pad is placed on a platen 18 having a flat surface in which an array of built-in pressure zones 20 is formed. Pressure zones provide pressurized fluid such as gas to the

under-side of the polishing pad to act as a cushion and prevent the pad from touching the platen during processing. By applying a varying gas pressure to the backside of the polishing pad from various zones, polishing rate on the corresponding locations of the wafer surface may be changed while pressing the surface of the wafer against the pad surface. The pressure zones 20 are often formed concentrically to apply local pressure on different sections on the surface of the wafer. During the CMP process, the wafer carrier 16 can also be rotated while the pad 12 is moved. The wafer 14 is pushed against the polishing pad 12 while rotating to accomplish material removal. Depending on the pressure distribution profile created on the backside of the pad, polishing rate of the corresponding regions on the wafer surface may be varied to achieve desired polishing on the wafer. For example, by increasing the pressure about the center of the wafer, higher polishing rates may be obtained at the center of the wafer surface. However, in such systems, pressure applied by the pressure zones of the platen onto different regions of the wafer is not entirely independent from one another. Pressure from neighboring pressure zones may interfere with each other. In fact, theoretically the center of the wafer should always see the highest pressure in the setup of Figure 1. Therefore, control for individual zones may not be very good.

[0005] As the brief review above shows, a need exists for a chemical mechanical polishing (CMP) system, which can provide accurate, stable and controllable polishing rates on various parts of a wafer.

SUMMARY

[0006] The present invention employs a flow assembly with a non-planar surface profile to apply fluid flow to a backside of a polishing pad to cause a polishing side of the polishing pad be forced against a workpiece surface during the chemical mechanical polishing of the workpiece. The fluid flow is applied to the polishing pad using a plurality of fluid zones placed in the non-planar flow assembly surface. The fluid flow zones may be arranged into any configuration or array in the flow assembly surface such as concentric or linear. Spaces or regions provided in between the zones may be used to substantially isolate the zones from the neighboring zones and may establish ventilation regions or drains for the fluid leaving the individual zones of the flow assembly.

[0007] The flow assembly surface may have any profile or topography, such as a raised profile or a recessed profile, which vary the gap between the flow assembly surface and the pad or the workpiece surface at selected locations. The gap between the backside of the polishing pad and the flow assembly surface of the present invention is defined as a variable gap. The varying profile of the surface of the flow assembly and the resulting variable gap between the backside of the pad and the surface of flow assembly provide a well-defined fluid distribution and pressure profile for each zone. Such well-defined fluid distribution and pressure profiles establish well defined polishing rates on the workpiece surface as the polishing pad polishes the workpiece surface.

[0008] In one embodiment of the present invention, material removal rate from the workpiece surface can be controlled by actively varying the flow assembly surface profile or topography by moving the fluid flow zones with respect to the pad or the workpiece surface, which adjusts the variable gap. In another embodiment, the material removal rate can be controlled by using a flow assembly with a fixed surface profile or topography, which keeps a fixed variable gap which is shaped by the fixed non-planar flow assembly surface and the polishing pad.

[0009] Accordingly in one aspect of the present invention, an apparatus for polishing a surface of a workpiece includes a carrier configured to hold the workpiece, a showerhead, having a non-planar surface, providing a variable gap between the non-planar surface and the surface of the workpiece and a polishing pad with a polishing side and a back side positioned within the variable gap. The polishing pad is configured to polish the surface of the workpiece with the polishing side when a fluid flow is applied from the non-planar surface to the backside. The fluid flow is applied from a plurality of fluid flow zones formed in the non-planar surface and the fluid flow zones are configured to move to cause a change in the topography of the non-planar surface. A feed back circuit induces a change in the topography of the non-planar surface in response to a change in a removal profile to yield a pre-determined removal profile.

[0010] In another aspect of the present invention, a method of controlling material removal rate from a workpiece surface is provided. The method includes the steps of holding the workpiece with a carrier, placing the polishing pad into the variable gap provided between a non-planar surface of a showerhead and the workpiece surface; emitting fluid from the non-planar surface of the showerhead onto backside of the pad to establish pressure; establishing relative

motion between the pad and the workpiece surface and removing material from the workpiece surface with polishing side of the pad.

[0011] These and other features and advantages of the present invention will be described below with reference to the associated drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

[0012] Figure 1 is a schematic view of a prior art chemical mechanical polishing apparatus;

[0013] Figure 2A is a schematic side view of an embodiment of a chemical mechanical polishing apparatus of the present invention including a showerhead with movable fluid flow zones;

[0014] Figure 2B is a schematic plan view of the shower head shown in Figure 2A;

[0015] Figure 3A is a schematic side view of the chemical mechanical polishing apparatus of the present invention shown in Figure 2A, wherein the fluid flow zones of the showerhead have been moved into a center high configuration to remove more material from center of a wafer;

[0016] Figure 3B is a graph showing variation of material removal across the diameter of the wafer surface when the shower head in Figure 3A with center high configuration is used;

[0017] Figure 4A is a schematic side view of the chemical mechanical polishing apparatus of the present invention shown in Figure 2A, wherein the fluid flow zones of the showerhead have been moved into a center low configuration to remove more material from edge of a wafer;

[0018] Figure 4B is a graph showing variation of material removal across the diameter of the wafer surface when the shower head in Figure 4A with center low configuration is used;

[0019] Figure 5 is a schematic side view of an embodiment of a chemical mechanical polishing apparatus of the present invention including a showerhead with stepped center high surface with fixed fluid flow zones;

[0020] Figure 6 is a schematic side view of an embodiment of a chemical mechanical polishing apparatus of the present invention including a showerhead with convex surface with fixed fluid flow zones;

[0021] Figure 7 is a schematic side view of an embodiment of a chemical mechanical polishing apparatus of the present invention including a showerhead with stepped center low surface with fixed fluid flow zones;

[0022] Figure 8 is a schematic side view of an embodiment of a chemical mechanical polishing apparatus of the present invention including a showerhead with concave surface with fixed fluid flow zones;

[0023] Figure 9 is a schematic plan view of a shower head having elongated fluid flow zones; and

[0024] Figure 10 is a schematic side view of a showerhead with fluid flow zones having variable surface topography.

DETAILED DESCRIPTION

[0025] CMP system of the present invention applies fluid flow from a flow assembly separated from a backside of a polishing pad with a variable gap to cause a polishing or processing side of the polishing pad be forced against a workpiece surface during the chemical mechanical polishing of the workpiece. The fluid flow may be applied to the polishing pad using a flow assembly that has a plurality of fluid flow zones placed in a flow assembly surface. The fluid flow zones may be arranged into any configuration or array in the flow assembly surface such as concentric or linear. Spaces or regions provided in between the fluid flow zones may be used to substantially isolate the fluid flow zones from the neighboring zones and may establish ventilation regions or drains for the fluid leaving the individual zones of the flow assembly.

[0026] The flow assembly surface may have any profile or topography, such as a raised profile or a recessed profile, which vary the gap between the flow assembly surface and the pad or the workpiece surface at selected locations. Accordingly, when the polishing pad is placed over the flow assembly, the gap between one or more zones and the backside of the polishing pad may be smaller than the gap between the backside of the polishing pad and the rest of the zones. Therefore, the gap between the backside of the polishing pad and the flow assembly surface of the present invention is defined as a variable gap. The variable gap between the backside of the polishing pad and the fluid flow zone forming the highest point on the flow assembly surface may be nearly zero or more than zero. The varying profile of the surface of the flow assembly and the resulting variable gap between the backside of the pad and the surface of

flow assembly provide a well-defined fluid distribution and pressure profile for each fluid flow zone. Such well-defined fluid distribution and pressure profiles, in turn, establish well defined polishing rates on the workpiece surface as the polishing pad polishes the workpiece surface.

[0027] In one embodiment of the present invention, material removal rate from the workpiece surface can be controlled by actively varying the flow assembly surface profile or topography by moving the fluid flow zones with respect to the pad or the workpiece surface, which adjusts the variable gap. In another embodiment, the material removal rate can be controlled by using a flow assembly with a fixed surface profile or topography, which keeps a fixed variable gap which is shaped by the fixed flow assembly surface and the polishing pad. Therefore, in this application, a gap between the flow assembly surface and the polishing pad is a variable gap which may be an adjustable or fixed variable gap. In either embodiment, in addition to variable gap feature, fluid flow rates at each zone may also be varied, in which case the process window within which removal rates are varied may be further widened.

[0028] In other words flow rate control and variable gap control become two important process knobs that can be varied independent from each other to control the profile of removal rate. After pushing the polishing pad toward the workpiece surface, the fluid from the zones exits the assembly, partially through the drain region if drains are used, thus reducing fluid flow effects on the neighboring zones. In this design, passages or drains between the zones for the used fluid may or may not be employed because the variable gap itself introduces differences between the pressures over the various zones with different gap values. Figures 2A through 4B exemplify two embodiments of flow assemblies or showerheads. In these embodiments, fluid flow zones z_1 , z_2 , z_3 and z_4 of the showerheads are movable. The gap between the polishing pad and the surface of the flow assembly is an adjustable variable gap, which may be adjusted by moving the zones with respect to the polishing pad. It should be noted that in these examples each zone is connected to a different fluid source. However, it is possible to practice this invention by connecting two or more or even all the zones to the same fluid source and then varying the adjustable gap to control the removal rate profiles.

[0029] Figures 2A-4B exemplify a chemical mechanical polishing system 100 having an embodiment of a flow assembly 102 or a showerhead of the present invention. As shown in Figure 2A, the showerhead 102 comprises a first fluid flow zone z_1 , a second fluid flow zone z_2 , a third fluid flow zone z_3 and a fourth fluid flow zone z_4 . In this embodiment, the showerhead

102 has four exemplary fluid flow zones, although the showerhead 102 may have any number of fluid flow zones to perform the present invention. As will be described more fully below, each fluid flow zone z_1 - z_4 provides a fluid flow, such as airflow, under a polishing belt 104 or a polishing pad, and force the polishing pad 104 against a front surface 106 of a wafer 108. Each fluid flow zone is configured to push the polishing pad onto definite or corresponding regions of the front surface 106 of the wafer, i.e., each zone has an approximate corresponding location on the front surface 106. If the air flow is kept constant for each fluid flow zone, the distance or the gap between a fluid flow zone and the polishing pad affects the force applied onto the front surface of the wafer by that individual fluid flow zone. Therefore, material removal rate from the corresponding locations on the front surface 106 depends on the magnitude of the gap between the polishing pad and the fluid flow zones.

[0030] As exemplified with dotted line, zones z_1 and z_2 , may each be moved with respect to the polishing pad 104 using a moving mechanism (not shown) to vary the gap between these zones and the pad or the front surface 106 of the wafer. As illustrated in Figures 2A-4B, in this embodiment, the gap between the polishing pad 104 and each fluid flow zone z_1 - z_4 can be varied to control the material removal rate on a front surface 106 of a wafer 108, and to obtain desired material removal profiles on the front surface 106. However, as will be described with reference to Figures 5-8, a shower head may also be pre-shaped with a desired profile having elevated or descended zones to achieve desired material removal profiles on a front surface of a wafer. Alternately, a design comprising pre-shaped zones with capability to move may also be employed.

[0031] During the material removal process, a wafer carrier 110 retains the wafer 108, preferably at a fixed elevation so that only the distance between the back surface of the polishing pad and the fluid flow zones vary. The polishing pad 104 may be any of a fixed-abrasive polishing pad, or a more standard polymeric polishing pad. The polishing pad 104 includes a first surface or a process surface 112 and a second surface or a back surface 114. The polishing pad 104 may preferably be tensioned by a tensioning mechanism (not shown). Process surface 112 of the polishing pad 104 polishes the surface 110 of the wafer during the CMP process. Material removal from the front surface 106 may be performed using a polishing solution or slurry, which may or may not contain abrasive particles. The front surface 106 of the wafer 108 may include a conductive layer such as copper or a dielectric layer that the material removal

process of the present invention is applied. The polishing pad 104 may be moved linearly, preferably bi-linearly, using a moving mechanism (not shown). Alternately, the polishing pad may be round and may be rotated like in standard rotary CMP tools. Exemplary CMP systems using bi-linear motion to polish surfaces are exemplified in the following patents. U.S. Patent No. 6,103,628 entitled Reverse Linear Polisher with Loadable Housing, U.S. Patent No. 6,464,571 Polishing Apparatus and Method with Belt Drive System Adapted to Extend the Lifetime of a Refreshing Polishing Belt Provided Therein, and U.S. Patent No. 6,468,139 Chemical Mechanical Polishing Apparatus and Method with Loadable Housing, which are owned by the assignee of the present invention.

[0032] During the CMP process of the present invention, an airflow through the showerhead 102 is applied onto the back surface 114 of the polishing pad 104. Application of the airflow to the polishing pad 104 may be performed using a plurality of fluid openings 116 formed through the fluid flow zones z_1 , z_2 , z_3 and z_4 . The fluid openings 116 may be arranged into any configuration or array with ventilation openings 118 among them. The ventilation openings 118 vent out the air used to push the pad against the surface of the workpiece, and optionally the ventilation openings may be connected to a vacuum system (not shown) for more efficient ventilation. The fluid openings 116 are formed through the fluid flow zones z_1 , z_2 , z_3 and z_4 to create a fluid flow distribution profile on the showerhead 102. As shown in Figure 2B, the fluid flow zones z_1 - z_4 may be formed concentrically and each zone may be connected to a fluid flow controller (not shown) to regulate fluid flow for each zone. In this embodiment, ventilation openings 118 are depicted as circular slits or circular gaps separating each zone. However, they may also be formed as holes.

[0033] In accordance with the principles of the present invention, by varying the distance between the individual fluid flow zones z_1 - z_4 and the polishing pad 104, the profile of material removal rate on corresponding areas of the front surface 106 of the wafer is effectively controlled and sharper removal profiles are obtained. Figure 3A exemplifies a center high configuration of the showerhead, which is formed by mechanically moving the zone z_1 and z_2 closer to the back surface 114 of the polishing pad 104. The center high configuration aims at removing more material from the center region of the front surface of the wafer compared to edge. In this configuration, surface s_1 of the first fluid flow zone z_1 is 0.5 to 5 mils, preferably 1 to 2 mils, higher than the surface s_2 of the second fluid flow zone z_2 . Similarly, the surface s_2 is

0.5 to 5 mils, preferably 1 to 2 mils, higher than the surfaces s_3 and s_4 of the third fluid flow zones z_3 and the fourth fluid flow zone z_4 . This vertical distance between the surfaces of the fluid flow zones will be called step height herein below.

[0034] As mentioned above, airflow towards the back surface 114 of the polishing pad 104 pushes the pad against the front surface 106 of the wafer 108 that is held and rotated by the wafer carrier 110. Accordingly, in this center high configuration, air from the zone z_1 applies more force per unit area to the polishing pad and the corresponding polished region on the front surface 106 of the wafer 108 when the first zone z_1 is elevated and placed at a first elevated position at proximity of the back surface 114 of the polishing pad 104. At the first elevated position, the gap between the back of the polishing pad and top surface of the first fluid flow zone is smallest in comparison to the other fluid flow zones of the shower head 102. The gap between the backside of the polishing pad and top surface of the first fluid flow zone or the highest point on the showerhead 102 may be nearly zero or microscopic. At this position, due to the small gap, the air from the first fluid flow zone z_1 is very effective and causes the most material removal from the front surface 106 of the wafer. Since the first fluid flow zone z_1 is across a center region of the wafer 108, highest material removal rate occurs at the center region of the front surface 106.

[0035] The second fluid flow zone z_2 is placed in a second elevated position in which the second fluid flow zone z_2 applies less force onto the polishing pad 104 than the force applied by the first fluid flow zone z_1 at the first position. In the second elevated position, the gap between the surface of the second fluid flow zone is larger than the gap between the surface of the first fluid flow zone z_1 and the back surface 114 of the polishing pad 104. The force applied by the air from the second fluid flow zone z_2 causes less material removal from the corresponding location on the front surface 106, which surrounds the center region of the front surface 106, due to the larger gap. Similarly, the third and the fourth fluid flow zones z_3 and z_4 cause less material removal from an edge region of the front surface 106 due to their relatively distant third and fourth elevated positions to the back surface 114 of the polishing pad 104. The step height between the neighboring zones can be adjusted to obtain desired variations of the center high configuration of the showerhead 102 and the resulting material removal profiles.

[0036] Figure 3B illustrates an exemplary material removal profile curve P_H for the wafer 108 when the wafer is polished with the center high shower head configuration shown in Figure

3A. This material removal profile may be changed by varying the step heights between the fluid flow zones. For example the curve may be made more convex, by increasing the step heights between the fluid flow zones z_1 - z_2 , z_2 - z_3 and z_3 - z_4 . Similarly, the profile curve may be made more flat by decreasing the step heights between the same zones. It is also possible to vary amount of fluid flow from the selected fluid flow zones to further adjust the material removal profile. In fact it is possible to use the center-high configuration shown in Figure 3A and get a flat removal profile by increasing flows to the outer zones. Therefore, this unique design reduces high sensitivity of removal rates to flow rate and opens up the process window for adjusting the removal profiles at will.

[0037] An alternative center-low configuration of the shower head 102 can be seen in Figure 4A, which can be achieved by moving the first and second fluid flow zones z_1 , z_2 away from the back surface 114 of the polishing pad 104 while leaving the third and fourth fluid flow zones z_3 , z_4 closer to the back surface 114 of the polishing pad. The center low configuration aims at removing more material from the edge region of the front surface if all flows at all zones are equivalent. In order to achieve center low removal profile, the first fluid flow zone z_1 is moved into a first declined position, which locates the first fluid flow zone away from the polishing pad. At the first declined position, the gap between the back of the polishing pad and top surface of the first fluid flow zone is largest in comparison to the other fluid flow zones of the showerhead 102. At this position, due to the large gap, the air from the first fluid flow zone z_1 is not effective and causes a smaller amount of material removal from the center region of the front surface 106.

[0038] The second fluid flow zone z_2 is placed in a second declined position in which the second fluid flow zone z_2 applies more force onto the polishing pad 104 than the force applied by the first fluid flow zone z_1 at the first declined position. In the second declined position, the gap between the surface of the second fluid flow zone is smaller than the gap between the surface of the first fluid flow zone z_1 and the back surface 114 of the polishing pad 104. The force applied by the air from the second zone z_2 causes more material removal from the corresponding location on the front surface 106, which surrounds the center region of the front surface 106, due to the smaller gap. However, the third and the fourth fluid flow zones z_3 and z_4 cause the highest material removal from an edge region of the front surface 106 due to their smaller gap with the back surface 114 of the polishing pad 104 in the third and fourth elevated positions. The step

height between the neighboring zones can be adjusted to obtain desired variations of the center low configuration of the showerhead 102 and the resulting material removal profiles. In this configuration, the step height range between the fluid flow zones z_1 - z_2 , z_2 - z_3 and z_3 - z_4 can be between the 0.1 to 10 mils, preferably 0.5 to 2 mils.

[0039] Figure 4B illustrates an exemplary material removal profile curve P_L for the wafer 108 when the wafer is polished with the center low shower head configuration shown in Figure 4A. This profile may be changed by varying the step heights between the fluid flow zones. For example the curve P_L may be made more concave, by increasing the step heights between the zones z_1 - z_2 , z_2 - z_3 and z_3 - z_4 . Similarly, the profile curve P_L may be made more flat by decreasing the step heights between the same zones. Profile may also be changed by changing the individual flows as discussed in association with Figure 3B.

[0040] In the above embodiments, the position of the zones can be configured using smart systems that can monitor removal profile during the material removal process. Accordingly, by utilizing an electronic feedback mechanism or control system, gaps may be automatically adjusted to get the desired removal profile. Such profile may be changed in-situ during the process or before processing each wafer.

[0041] Figures 5 through 8 exemplify various configurations of pre-shaped or fixed surface profile flow assemblies or showerheads. In these embodiments, fluid flow zones z_1 , z_2 , z_3 and z_4 of the showerheads are integrated and are not movable, although they could also be made movable. The gap between the polishing pad and the surface of the flow assembly is a fixed variable gap, which is shaped by the fixed non-mobile profile or topography of the flow assembly surface and the back surface of the polishing pad. Figure 5 shows a center high showerhead 200 having a center high zone profile, which is formed using a predetermined step height between the neighboring zones. Air holes 202 are formed through the fluid flow zones z_1 , z_2 , z_3 and z_4 , and ventilation openings 204 are placed between the fluid flow zones. In this embodiment, the fluid zones are shaped as radially descending steps. A top surface 201 of the showerhead 200 has generally a stepped convex shape. Therefore, the gap between the top surfaces of the fluid flow zones z_1 , z_2 , z_3 and z_4 and the back surface 114 of the polishing pad radially expands, being smallest at the first fluid flow zone z_1 but largest at the fourth fluid flow zone z_4 . This characteristic of the showerhead 200 can be seen in an alternative center high showerhead 300 shown in Figure 6. In this alternative embodiment, rather than the step structure

shown in Figure 5, top surfaces of the zones z_1 - z_4 are combined into a convex surface 301. Air holes 302 are formed through the fluid flow zones z_1 , z_2 , z_3 and z_4 , and ventilation openings 304 are placed between the fluid flow zones. Use of the shower heads 200 and 300 give similar center high material removal characteristics demonstrated by the curve P_H in Figure 3B. This profile may be changed by varying the step heights between the fluid flow zones, the curvature of the surface 301 or the flows in individual zones.

[0042] Figure 7 shows a center low fixed showerhead 400 having a center low zone profile, which is formed using a predetermined step height between the neighboring zones. Air holes 402 are formed through the fluid flow zones z_1 , z_2 , z_3 and z_4 , and ventilation openings 404 are placed between the fluid flow zones. In this embodiment, the fluid zones are shaped as radially ascending steps. A top surface 401 of the showerhead 400 has generally a stepped concave shape. Therefore, the gap between the top surfaces of the fluid flow zones z_1 , z_2 , z_3 and z_4 and the back surface 114 of the polishing pad radially narrows down, being largest at the first fluid flow zone z_1 but smallest at the fourth fluid flow zone z_4 . This characteristic of the showerhead 400 can be seen in an alternative center low showerhead 500 shown in Figure 8. In this alternative embodiment, rather than the step structure shown in Figure 7, top surfaces of the zones z_1 - z_4 are combined into a concave surface 501. Air holes 502 are formed through the fluid flow zones z_1 , z_2 , z_3 and z_4 , and ventilation openings 504 are placed between the fluid flow zones. Use of the shower heads 400 and 500 gives similar center low material removal characteristics demonstrated by the curve P_L in Figure 4B. This profile may be changed by varying the step heights between the fluid flow zones, the curvature of the surface 501, or the flows in individual zones.

[0043] Although in the above embodiments flow assemblies are defined as round with concentric zones, a showerhead 600 may be elongated, for example shaped as a rectangle, as shown in Figure 9. Zones z_1 - z_4 may be shaped as rectangular strips or bars having fluid openings 602. As in the above embodiments, ventilation openings 604 or slits can be between the zones z_1 - z_4 . Zones can be movable or fixed having center high or center low configurations. A cross section of the showerhead 600, taken along the line B, can be any of the shower head cross sections or side views shown in Figures 2A, 3A, 4A and 5-8. In this embodiment, the gap between surface of the shower head 600 and the polishing pad held above it may be an adjustable variable gap or a fixed variable gap, which are described above.

[0044] Figure 10 exemplifies an alternative flow assembly or showerhead 700 placed under a polishing pad 702. Zones z_1 - z_2 may preferably be separated by ventilation openings 703, although ventilation openings may not be used. In showerhead 700, each exemplary fluid zone z_1 - z_2 has a variable topography itself such as high surfaces S_1 and low surfaces S_2 . In this example, due to the variable topography of the zones, each zone z_1 - z has its own variable gap with the backside of the pad 702.

[0045] In the above showerhead embodiments, depending on the vertical position of the fluid flow zones, the gap established between the showerhead and the back surface of the polishing pad varies. As described above, non-planar top surface of the showerhead varies the gap between the top surface of the showerhead and polishing pad. For example, among many others, the gap can be large at the edges but smaller at the center of the showerheads or, alternatively, the gap can be smaller at the edges but large at the center at the showerheads. The gap may be nearly zero between the highest point on the showerhead and the backside of the polishing pad. As opposed to the prior art planar top surface platens, non-planar top surface character of the showerheads and resulting gap variations provide escape passages for the used air. This is not possible with the prior art systems. Therefore, in the above embodiments, the use of ventilation openings is optional and the showerheads can be manufactured without ventilation openings. Although the present invention is described using a CMP example, the above embodiments can be used to perform an electrochemical mechanical polishing (ECMP) process. In ECMP, during the material removal with a polishing pad, an electrical potential difference is applied between the conductive surface and a cathode electrode while an electropolishing solution wets both. The cathode may be the showerhead or a separate electrode.

[0046] Accordingly, the present invention provides substantially enhanced control for each zone. The present invention provides distinct fluid flow rate distribution profiles. Such well-defined and uniform fluid distribution, in turn, establishes well-defined polishing rates on the substrate as the polishing pad polishes the workpiece surface.

[0047] Although various preferred embodiments and the best mode have been described in detail above, those skilled in the art will readily appreciate that many modifications of the exemplary embodiment are possible without materially departing from the novel teachings and advantages of this invention.